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Development of the Plastic Melt Waste Compactor- Design and Fabrication of the Half-Scale Prototype

Gregory S. Pace
Lockheed Martin Technical Operations

John Fisher
NASA Ames Research Center

ABSTRACT

A half scale version of a device called the Plastic Melt Waste Compactor prototype has been developed at NASA Ames Research Center to deal with plastic based wastes that are expected to be encountered in future human space exploration scenarios such as Lunar or Martian Missions. The Plastic Melt Waste Compactor design was based on the types of wastes produced on the International Space Station, Space Shuttle, MIR and Skylab missions. The half scale prototype unit will lead to the development of a full scale Plastic Melt Waste Compactor prototype that is representative of flight hardware that would be used on near and far term space missions. This report details the progress of the Plastic Melt Waste Compactor Development effort by the Solid Waste Management group at NASA Ames Research Center.

INTRODUCTION

Hardware is being developed at NASA Ames Research Center capable of processing and handling plastic based wastes that are an analog of wastes expected to be encountered on near and far term space missions.

The hardware that has been developed to manage the plastic based waste is called the Plastic Melt Waste Compactor (PMWC). The PMWC uses heat and compaction to achieve high volume reduction and can also be adapted to sterilize or stabilize the waste. The PMWC can also be modified to recover water entrained in the food residues that remain on food packaging.

Studies were performed at NASA Ames Research Center to characterize the degree of volume reduction possible of a variety of plastic based wastes defined in the Solid Waste Model presented by K. Wignarajah, February 19, 2003 [1] using the PMWC technology. The Solid Waste Model is representative of the waste types that are expected in future manned space activities such as a moon or mars mission and is based on current and past missions such as Skylab, Mir, Space Shuttle and the International Space Station.

Currently astronauts on the International Space Station (ISS) manually compact waste items by holding a waste container in their hands and compacting the waste with their feet. This yields a low compaction ratio and is inconvenient for the crew. This prompted the study of the feasibility of PMWC.

For space missions beyond earths orbit, re-supply is not an option and the conservation and recovery of resources and containment of biological contaminants is a critical issue. Also, it is desirable to reduce the spacecraft volume needed for storage of non-recoverable waste products. It is assumed that unprocessed waste products will not be stored in the same containers as the food due to the possibility of contamination. Consequently a separate container or compartment must be incorporated into the spacecraft design. The extra volume added to the spacecraft results in an increased spacecraft mass. The cost of this mass addition is compounded in spacecraft such as a Mars transit vehicle because larger propulsion systems will be required to accelerate and decelerate the extra mass.

The solution that was proposed to manage the plastic waste products and associated food residue was the Plastic Melt Waste Compactor that minimizes volume by compaction of partially or fully melted plastic based wastes. The PMWC design incorporates features for the stabilization and sterilization of the food contaminated waste and removes the entrained water.

BACKGROUND COMPACTION STUDIES

NASA has investigated the use of compaction as a means of waste management for space exploration in the past. Industrial Ecology, INC. of Los Angeles, CA. built a prototype compactor for NASA in 1973 but the development of compactor did not continue from that point [1]. A manual compaction unit was also manufactured and tested on the space shuttle but was found to be difficult to operate and the astronauts ended up resorting to compacting waste into a can with their feet.

The Navy developed a plastic processing unit called the Compress Melt Unit(CMU) in order to comply with environmental regulations outlined in the MARPOL Annex V report (an international study on Maritime Pollution)[2]. Prior to the use of the CMU, bagged trash was thrown directly into the ocean. Annex V required that vessels in international waters cease dumping plastic waste into ocean. This led to a large accumulation of trash that required an excessively large storage volume. The waste also presented a handling problem in the un-compacted, bagged state. Standard compaction methods required that the compacted trash be bagged. The trash bags were prone to tearing; and consequently a release of odors from biologically active waste would occur and could even escape from an un-punctured trash bag.

The Navy's CMU is capable of encapsulating waste in a solid plastic disk that is easy to handle and more compact then wastes compacted by current means. The CMU was designed to deal with a much larger volume of trash then would be encountered on a space mission. The CMU processes 326.4 kg/day at a system weight of 2490 kg [3]. The size and power requirements of the Navy plastics waste processor system was not a concern to the Navy since the system was designed to operate on frigate size and larger ships. The CMU was not designed to operate in an enclosed environment such as would exist in a spacecraft, space station, or extraterrestrial planetary base. A unit designed to operate in the space environment would have to deal with issues such as odor and noxious or toxic off gassing control, resource recovery, compactness, low mass and energy efficiency of the design, which is much more critical for space exploration.

PLASTIC MELT WASTE COMPACTOR HARDWARE AND PROCESS DESCRIPTION

The PMWC was designed to approach the limit of possible volume reduction via compaction methods. The design also incorporated features such as a sealed waste processing chamber to perform stabilization/sterilization procedures using Waste Encapsulation, Moist Heat Sterilization and Dry Heat Sterilization as well as the capability to remove moisture from the waste for resource recovery.

VOLUME REDUCTION, STERILIZATION AND WASTE ENCAPSULATION

The PMWC uses compaction pressure in combination with heat to maximize volume reduction. For LEO missions it may be desirable to minimize waste volume and simplify processed waste handling without the need for a high degree of sterilization. For such scenarios the power requirements and process time can be greatly reduced. The final product can be heated to a level that only melts the outer surface of the plastic waste that is in the compaction chamber, encapsulating any microbes within the plastic disk and sterilizing the surface. This level of waste stabilization may be sufficient for ISS were trash is routinely removed at shorter intervals then would be possible on long duration missions. The mechanisms by which great volume reduction can be achieved without the complete or even partial melting of the plastic is described below.

The heat addition to the compaction process helps to lower the plastic yield point so that the compressed plastic retains its deformed shape, which reduces the tendency for plastic to decompress (commonly known as spring back) after the load is removed. Honeywell Plastics Petra 130 chopped fiber-reinforced nylon has a tensile breaking strength of 22,500 psi at 23°C. At 80°C the tensile breaking strength is reduced by 48% to 11,600 psi [4]. This behavior is typical of plastics in general, although the effects are even more pronounced for types of plastics that are encountered on space missions.

Further volume reduction is achieved by bringing the plastic within a temperature range that increases the tendency for the plastic to bond under pressure. This results in even greater volume reduction by the additional reduction of spring back. This is useful for applications where sterilization is not required allowing the heat energy requirements to be reduced.

The sterilization of waste may be necessary for crew health and safety during long duration missions. Crew quarters of spacecraft and extraterrestrial bases are enclosed and microbes could quickly reach dangerous levels if not properly treated.

Sterilization of waste is an important issue for missions involving the search for evidence of life. Contamination of the environment where the search for life is being conducted is possible with the inadvertent introduction of microbes. It may be required that all wastes be sterilized even if it is determined that the potential micro-biological activity presents no hazard to the crew.

PMWC DEVELOPMENT TESTING AND DESIGN

PRIOR TESTING – Tests were performed at NASA Ames Research Center to evaluate the technical feasibility of the PMWC and provide critical information for the design of a first generation lab-scale prototype.

The tests were designed to determine the volume reduction as a function of different percentages of plastics waste types and other waste components when subjected to different temperatures and pressure loads at sub-bonding temperatures, Seal Initiation Temperatures (SIT) and temperatures above the SIT as well as the effects on the bonding and encapsulation of hydrated food waste composites.

An example of a processed plastic based waste disk is shown below in figure 1. The disk in figure 1 is typical of the types of waste disks that were produced using this process. The non-plastic waste is fully encapsulated and the disk has the consistency of solid plastic. This final product is tough and virtually impervious to puncture.

Figure 1. Plastic Encapsulated Mixed Waste

WASTE AND ENERGY STREAMS - The waste and energy input and output streams of the PMWC are shown in figure 2. Food contaminated plastics and other waste types including gloves, duct tape, paper and possibly constitute the types of waste that will be processed by the PMWC. The PMWC produces a plastic disk that encapsulates the non-plastic constituents of the waste input stream using the plastic component of the waste stream. The temperature and cycle times that are required to encapsulate the waste will evaporate the water content in most cases.

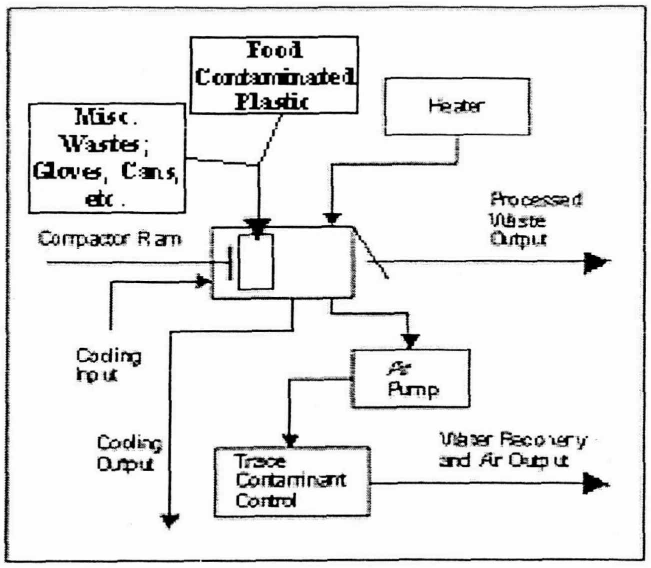

Figure 2. PMWC Input and Output Streams

VOLUME SAVINGS AND ESM ANALYSIS – A volume savings and ESM analysis was done for the PMWC based on the Solid Waste Model. The waste model used data from Skylab, Mir, Space Shuttle and International Space Station missions to estimate the waste production for a 6-person crew [1]. Information was taken from the Skylab data and the Maritime Pollution Act (MARPOL, ANNEX V, 1996) study performed for the U.S Navy, to estimate manually compacted trash densities [1][2]. Manually compacted densities were defined in the MARPOL study as the average trash densities of typical office trash cans. The average density reported in the MARPOL study was 4 lb/ft^3 (64 kg/m^3). Skylab astronauts stowed their trash in an empty liquid oxygen tank. The final density of the trash packed into the Skylab trash storage container was 70 kg/m^3. The MARPOL data and Skylab data were almost identical for manually compacted trash density average of 67 kg/m^3. Both the MARPOL and Skylab data corresponded with the data gathered during the plastic waste characterization testing. Data on the ESM of the Plastic Waste Melt Compactor is provided in table 1 in the appendix.

The largest potential ESM reduction of the Life Support System effected by the PMWC comes from the reduction of storage volume and from water recovery. The food residue that is stuck to the food packaging is difficult to efficiently remove. Consequently, the plastic and food scraps are processed together and the water is not recovered.

Current ESM figures place shielded volume at 215.5 kg/m^3 [5]. The average volume reduction from the plastic waste characterization tests that used the complete waste composite was 11:1(see tables 2 through 4 for results of plastic volume reduction and encapsulation using a waste analog based on the Solid Waste Model). This indicates a compacted waste volume reduction greater then 32.4 m^3 to 3.2 m^3 for the total Mars Transit portion of the mission. A factor of 10 reduction was used

as conservative estimate for calculating the volume savings figures. The current ESM value of 32.4 m^3 of shielded volume is 6982 kg. After plastic melt processing, the ESM value drops to 698 kg for a reduction of 6284 kg (see table 1 in the appendix).

The volume savings potential of the PMWC would affect the ESM value of the type of storage volume selected.

The use of shielded volume is assumed because technical issues regarding the use of unshielded volume are unknown. The areas of uncertainty in the use unshielded volume are trash accumulation during a solar event which would prevent the crew from accessing the unshielded stowage area and the final mass of an unshielded volume to make it safe for the crew to enter. The mass of an unshielded volume after meeting all the requirements for a manned pressure vessel will make maximized volume reduction an important factor in space mission cost reduction.

The potential for water recovery is high based on the assumption that water will be recovered for reuse in the space craft life support system. According to the Solid Waste Model, 1.6 kg to 1.8 kg of water per day for a six-person crew is entrained in the wastes that have been used to model the PMWC energy requirements.

The PMWC ESM figures in table 1 in the appendix include the energy to heat and cool the solid wastes including the water and also the energy to evaporate the water. The energy to compact the waste was also included in the total energy consumption figure.

PROTOTYPE DESIGN – The first prototype of the PMWC is intended to test design concepts that would eventually lead to a low ESM waste processor capable of carrying out a variety of functions. The primary goals of the first prototype are:

- To be able to compact, bond and/or encapsulate a variety of waste types including hydrated food
- To determine the functionality of design concepts and systems to be incorporated into the compactor
- To test the ability of the PMWC to prevent odors or noxious gases from escaping the input and output doors during use
- To determine the amount of steam, VOC's and other contaminants generated during the melting/compaction process
- To measure the stability and level of disinfection of the final waste product

The objectives below had been considered for the design of the first prototype but were deemed more important for the development of a second generation prototype. The goals for a second generation prototype are as follows:

- The reduction of mass, volume and power consumption
- The ability of the hardware to meet differing requirements and capabilities such as compaction without bonding, compaction at the SIT, encapsulation, disinfection or sterilization and water recovery
- The consideration and analysis of secondary systems that could be incorporated into the unit such as trace contaminant control and water recovery

First Experimental Prototype Description – Figure 3 shows a three dimensional computer generated model of the PMWC without an enclosure.

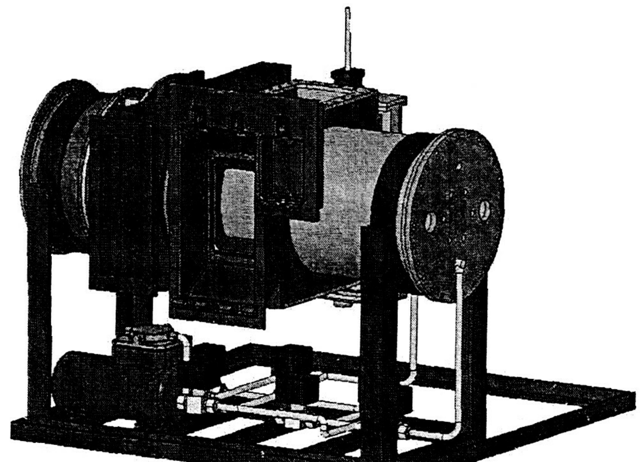

Figure 3. Front view of the PMWC without Enclosure

The PMWC was designed to compact and encapsulate the plastic waste, and to disinfect or sterilize the waste with no design changes. The lab-scale prototype is nearly cubic in shape with the enclosure on (not shown). The external housing dimensions of the prototype PMWC are approximately 31" x 31" x 31" (0.5 m^3) for an 8 inch diameter compaction chamber. The lab-scale prototype's mass is approximately 60 kg.

Features Of Interest

The compaction force is provided by a unique design that uses the compaction cylinder as the actuator as shown in figure 4, 5 and 6 below. Figure 4 shows the piston face(black) that comes into contact with the waste. The piston is eight inches in diameter. Two one-inch wide graphite impregnated Teflon bushings are used to guide the piston. Graphite impregnated spring loaded Teflon seals are used to seal the piston pressurization chamber and the processing chamber. A quarter-inch thick virgin Teflon separator is used to isolate the heated piston face from the non-heated gold Allodyned piston skirt.

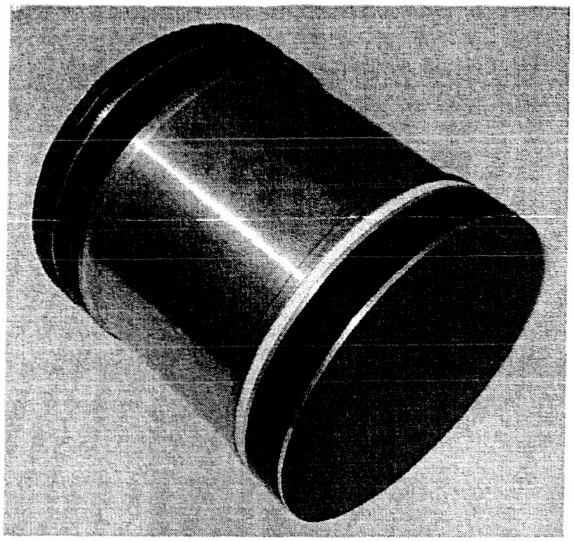

Figure 4. Compaction Piston Face View

Figure 5 shows the internal surface of the processing chamber that contacts the piston seals and bushings. The waste does not come into contact with the seals which are at the back of the piston. The design uses the piston and processing chamber as both the actuator and the compression unit. The use of the compaction cylinder with its relatively large piston face surface area produces high compaction forces at low air pressures. This method is lightweight because it utilizes the existing piston structure and processing chamber without the additional mass of a separate actuator. This allows the compactor to be operated at pressures below 100 psi for increased safety.

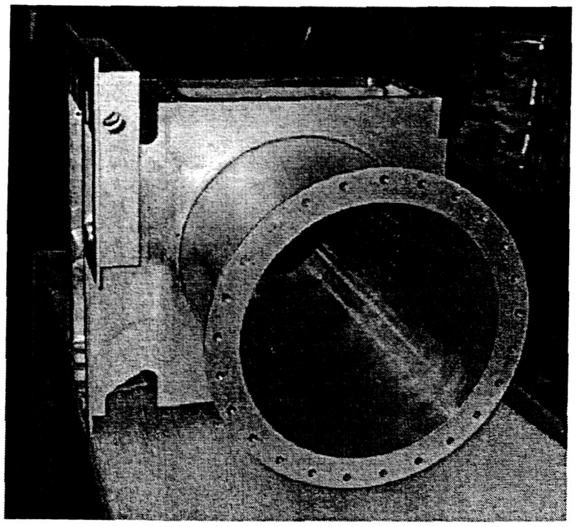

Figure 5. Rear View of the Processing Chamber showing Piston Seal Surfaces

Figure 6 shows a rear view of the compaction piston. The red surface inside the piston is a flexible silicon heater. The heated piston face thermal isolator made of white virgin Teflon is clearly visible in figure 4. The orientation of the piston shown in figure 6 matches that of the processing chamber shown in figure 5.

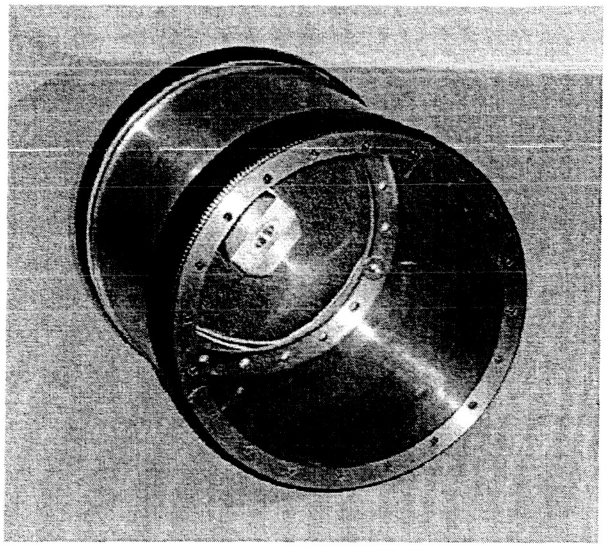

Figure 6. Rear View of Compaction Piston

The PMWC uses a small, light weight oil-less combination air compressor/vacuum pump to produce the compaction piston forces and evacuate the compaction chamber (see figure 7 below).

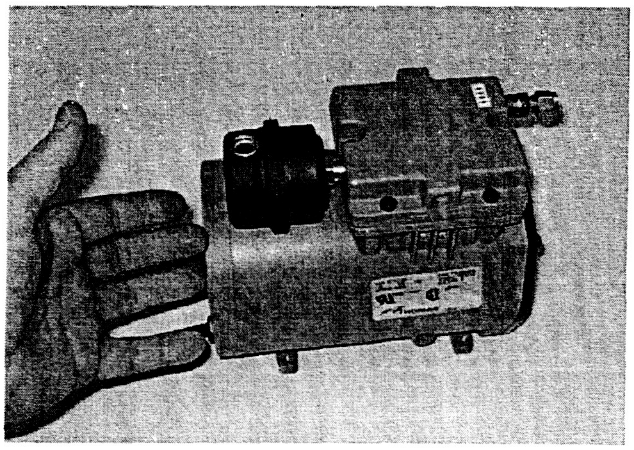

Figure 7. Oil-less Compressor used for the PMWC

The compactor was designed to prevent odors or noxious gases from escaping. This is a critical design element for a higher Technology Readiness Level (TRL) compactor prototype. A flight like prototype needs to demonstrate the ability to operate in an enclosed environment.

A processing chamber evacuation valve was designed to allow bi-directional sealing with a zero-differential pressure and a large orifice of 3.8 inches in diameter. The large orifice allows the use of a ventilation fan to draw heated air and off-gassed materials from the processing chamber. After an extensive search for a commercially available valve that was capable of bi-directional sealing at zero-differential pressure with a large orifice, it was decided that a custom designed valve would need to be developed. The only commercially

available valves that were found that had the aforementioned capabilities were voluminous and massive and weighed almost as much as the rest of the major components combined. The valve uses a lightweight linear actuator motor as shown in figure 8 below.

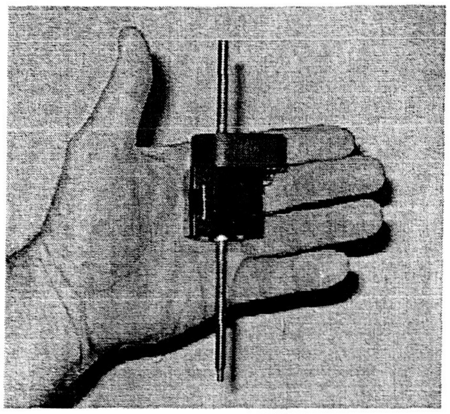

Figure 8. Lightweight Thru-Center Actuator used for PMWC Processing Chamber Evacuation Valve

The actuator in figure 8 consumes 4.9 Watts with a maximum recommended linear thrust of 50 lbs at a weight of only 150 grams. The Thru-Center feature allows for long actuation strokes limited only by the length of the threaded actuation rod. The actuator attaches to the valve housing as shown in figure 9. The actuator rod attaches to the Sealing Guide Plate Shown in Figure 10. Specially designed pins (not shown) attach to the Sealing Plate Guide and protrude into the slots on the Cam-Actuated Sealing Plate shown in figure 12.

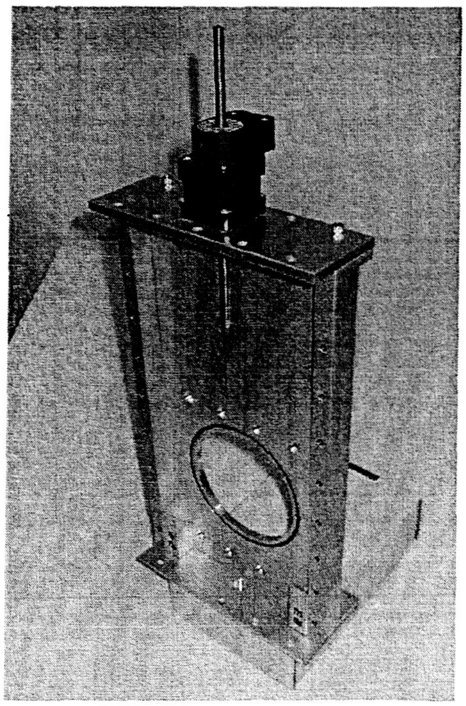

Figure 9. The Processing Chamber Evacuation Valve Housing and Actuator

The Cam-Actuated Sealing Plate, shown in figure 10, is pressed against an o-ring face seal shown in figure 11. The o-ring is retained by a half-dovetail groove. The Cam-Actuated Sealing Plate is actuated linearly through the majority of the stroke until the point of closure. At the end of the Cam-Actuated Sealing Plate's stroke, the plate engages stops which redirect the motion of the plate to approach the o-ring seal in a direction near normal to the seal face plate. The purpose of the normal direction approach to the o-ring is to minimize seal rolling which is a problem in slide entry gate type valves that use soft-sealing material. The sliding entry that is common in many gate valves forces the use of a hard sealing material. To acquire the necessary seal quality at lower pressures with a hard seal material requires a large interference between the sealing plate and seal material. As a result of the high interference forces, a much larger actuator motor is required increasing the overall mass, volume and power requirements of the PMWC.

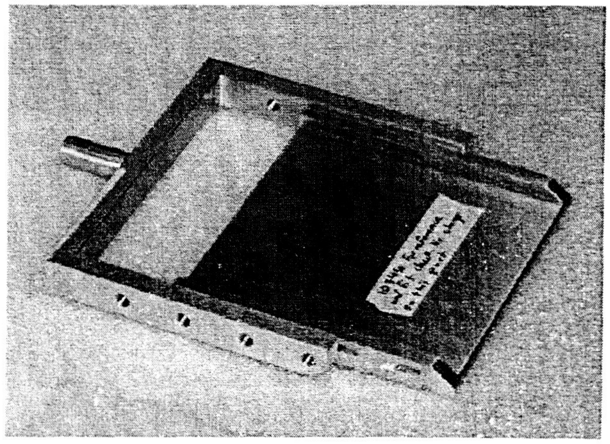

Figure 10. Image of Cam-Actuated Sealing Plate and Sealing Plate Guide

As the angled ends of the sealing plate shown in figure 10 and 12 come into contact with the angle stops shown at the bottom of figure 11, a cam action occurs that enables the sealing plate to remain in the closed configuration without the use of power.

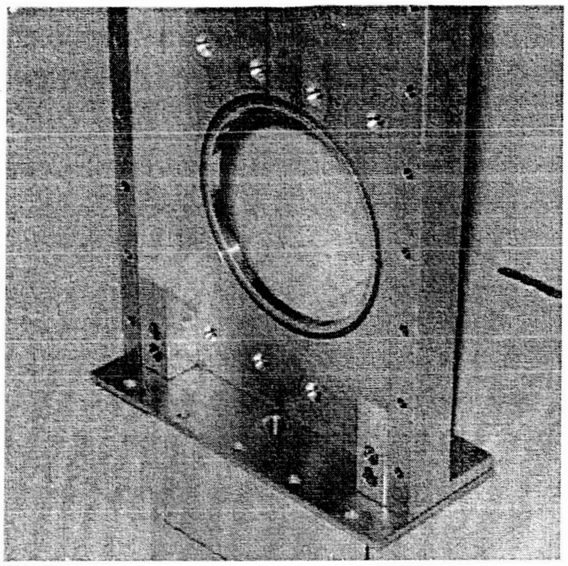

Figure 11. Close-up View of the Evacuation Valve O-ring and Sealing Plate Stops

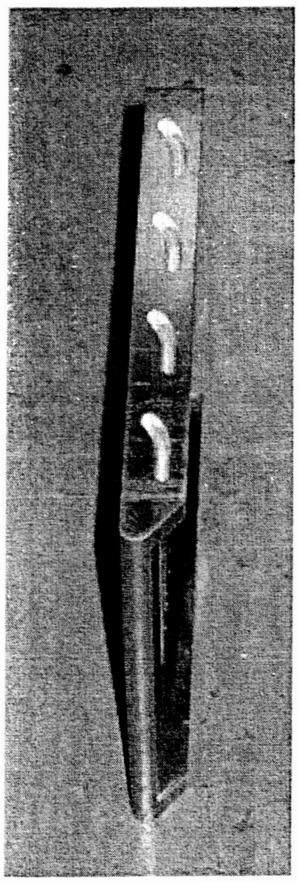

Figure 12. Close-up View of Sealing Plate with Cam-Lock Grooves

During the waste treatment process a second piston termed the Rear Piston is constrained in the processing chamber from the direction shown below in figure 13.

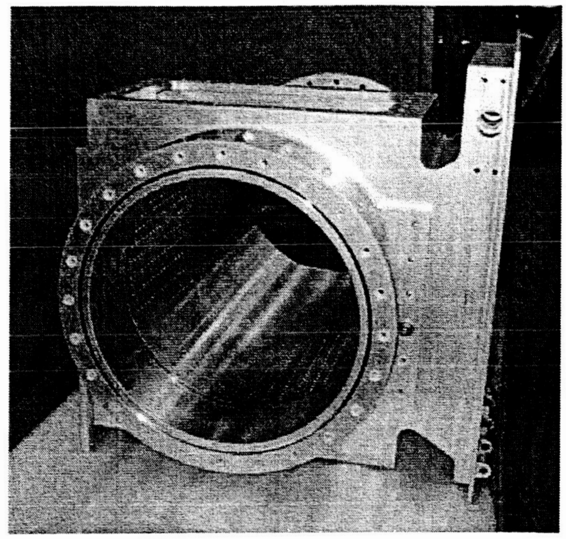

Figure 13. Front View of the Processing Chamber

The piston is restrained by a lock-ring, shown in figure 14, that is engaged during the waste input and processing phase of the waste treatment process.

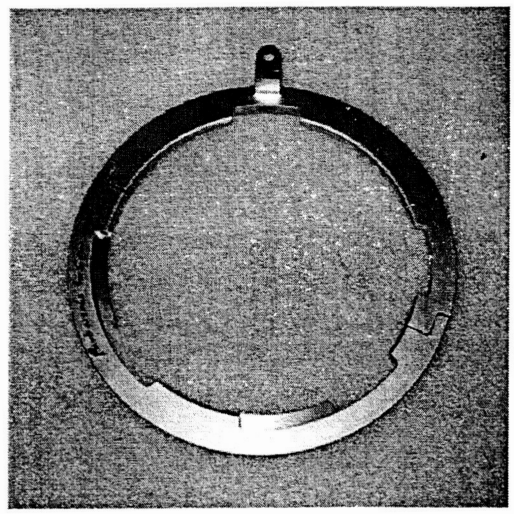

Figure 14. The Rear Piston Locking Restraint Ring

The lock-ring goes around the Rear Piston Guide Cylinder shown on the right in figure 15 and also shown in figure 16.

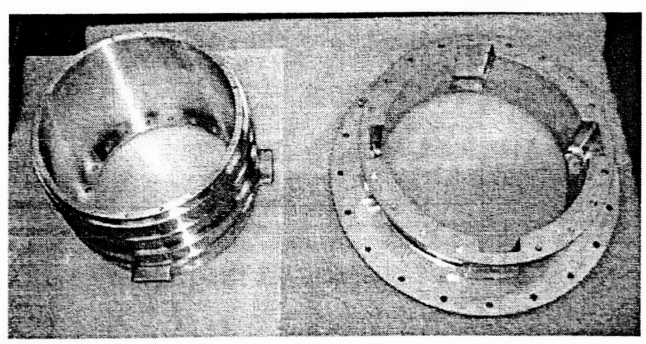

Figure 15. The Rear Piston Skirt and Rear Piston Guide Cylinder

When the tabs of the Rear Piston Skirt are in contact with the large flange on the Rear Piston Guide Cylinder the Rear Piston Locking Restraint Ring is rotated restraining the Rear Piston against movement. The restraint functions in a power-off mode meaning that power is needed only to actuate the restraining mechanism, not to maintain its restraining capabilities.

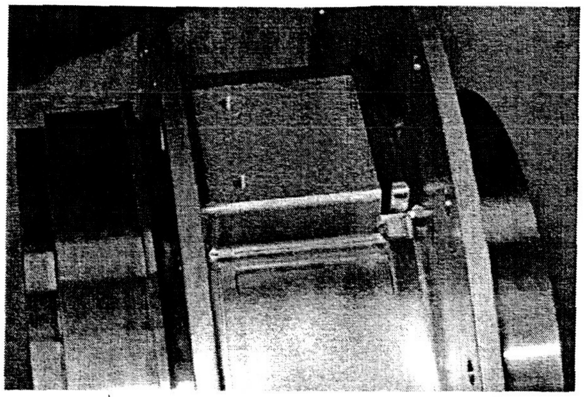

Figure 16. The Rear Piston Skirt inside the Rear Piston Guide Cylinder

After the disk is processed it is removed from the processing chamber by the Disk Ejection Pusher shown below in figure 17.

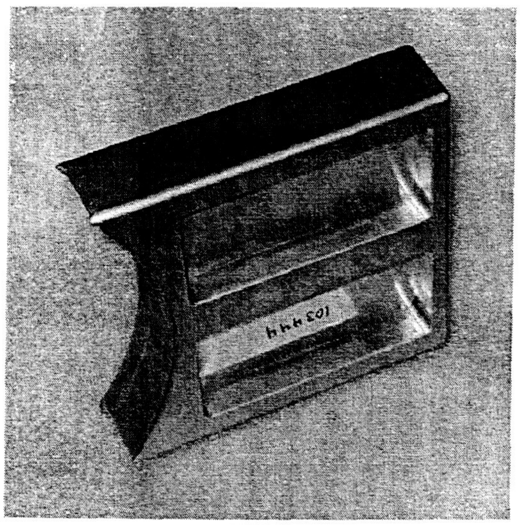

Figure 17. The Disk Ejection Pusher

The cylindrical surface of the Disk Ejection Pusher that comes into contact with the waste disk has shoveled edges to initiate the un-sticking of the disk from the piston faces (see figure 18).

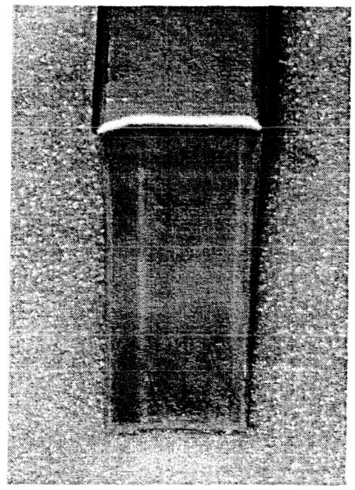

Figure 18. Close-up View of Disk Ejection Pusher Showing Shoveled Edges

After the waste has been processed, the rear piston is unlocked and free to retract into the rear piston chamber as the main compaction piston moves the plastic disk into the disk removal chamber. When the main compaction piston reaches the end of its stroke, the disk ejection pusher is activated and dislodges the plastic disk from the piston and moves it into position to be removed from the Disk Ejection Chamber by the operator (see Disk Ejection Chamber figure 19).

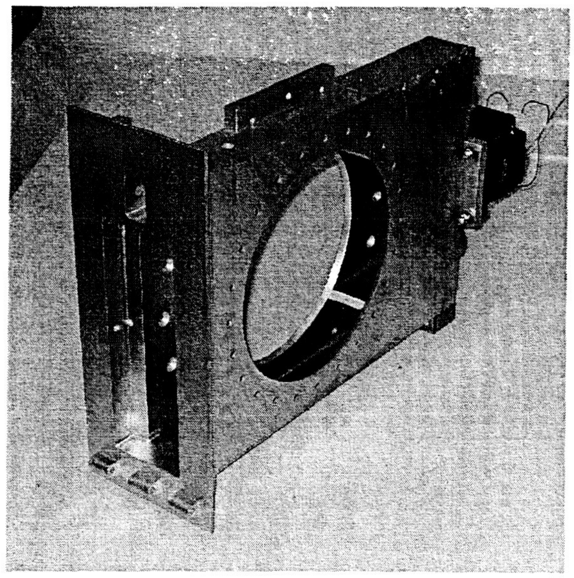

Figure 19. The Disk Ejection Chamber

After the disk reaches the standard NASA safe touch temperature of 40°C an indicator light signals that the plastic disk is ready for removal. After the disk is removed by the operator the PMWC automatically resets itself and places the pistons in the trash input position.

The first prototype allows the sampling of exhaust gases. The amount of moisture in the exhaust is measured by a humidity sensor to determine if and when the waste samples are dry.

The compactor's nominal operation functions will be automated with a simple single button operation after the completion of the initial testing with manually operated valves and controls. This will reduce crew-time interaction. The parameters of the processor cycles can be changed via a controller access panel.

A second generation prototype would concentrate on mass, volume and power reduction. The intention of the first prototype is to demonstrate the functionality of the design and to examine any design or process issues that may arise out of testing.

CURRENT ACTIVITIES

Testing of individual components has been performed to determine if the fabrication of the PMWC was according to specification. At this time of writing out of tolerance components are being fixed or replaced by the fabricator, D&H Manufacturing. Testing will resume after the receipt of the components mentioned above. The initial testing will focus on the mechanical functionality of the fully assembled PMWC. The resumption of testing will focus on the key areas below:

- The extension and return dynamics of the compaction pistons.
- The sealing capabilities of the custom valve and processing chamber.
- The ability to remove the processed disk from the processing chamber and compaction pistons.
- The functionality of the rear piston locking mechanism.

Concurrently, off-gassing studies of the waste types defined by the Solid Waste Model are being conducted at NASA Ames Research Center. The tests are designed to collect critical data on the composition, quantity and discharge rate curve of the wastes under the different conditions listed below:

- At the standard Dry Sterilization Temperature of 177°C.
- At a selected temperature of 135°C for Moist Heat Sterilization.
- At a temperature of 55°C and 2.3 PSIA (conditions selected for low temperature water removal).

The varying rate of off-gassing is important for determining optimal process times for the heating, compaction, drying and stabilization/sterilization processes. The information being collected on the composition and quantity of the materials being off-gassed is key in determining the best method of trace contaminant control.

CONCLUSION

Prior testing at NASA Ames Research Center have demonstrated the technical feasibility of dealing with the plastic based waste types defined in the Solid Waste Model using heat aided compaction. The testing showed that it was possible to completely encapsulate non-plastic wastes using the plastic percentages defined in the Solid Waste Model.

Extremely high volume reductions greater than 10:1 were achieved for a variety of plastic based wastes. The data collected during this testing was used to design the PMWC prototype. The initial Manufacturing of the PMWC was completed and the hardware is being adjusted to correct for manufacturing inconsistencies.

After the return of the PMWC hardware, testing will commence to evaluate the areas of refinement that will be needed to produce a full scale prototype.

According to the data gathered up to this date, the PMWC mass and functionality approach that of the conceptual analysis that was conducted prior to it's manufacture. More detailed and conclusive data will be gathered after receipt of the corrected hardware.

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CONTACT

Gregory S. Pace
B.S. Mechanical Engineer
Lockheed Martin Technical Operations
NASA Ames Research Center
Moffett Field, CA. 94035-1000
(650) 604-4719
gspace@mail.arc.nasa.gov

John W. Fisher
Lead Engineer, Advanced Life Support
Bioengineering Branch (Code SLB)
NASA Ames Research Center
Phone: 650-604-4440
john.w.fisher@nasa.gov

ADDITIONAL SOURCES

The sources listed below were used to develop the Solid Waste Model by K. Wignarajah [1]

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Definitions, Acronyms, Abbreviations

ESM: Equivalent System Mass

ISS: International Space Station

PMWC: Plastic Melt Waste Compactor

SIT: Seal Initiation Temperature

Spring-Back: The degree at which compressed waste decompresses after the load or pressure that causes compression is removed.

Stabilization: Generally stabilization means resistant to change of condition. For life support systems it is also frequently implied that the stable chemical and biological condition is one that will not adversely affect crew safety.

Sterilization: The removal or destruction of all microorganisms, including pathogenic and other bacteria, vegetative forms and spores.

TCCS: Trace Contaminant Control System

TRL: Technology Readiness Level

APPENDIX

Plastic Waste Processor ESM for Mars Transit						
(This assumes that the Mars transit total round trip time is 360 days)						
Parameter	Units	ESM factor	1st experimental prototype equipment mass, daily average power, cooling and volume	ESM Values for 1st experimental prototype not optimized for mass or power reduction	Full scale prototype equipment mass, power, cooling and volume projections (based on 1st experimental prototype)	ESM projections for full scale prototype not optimized for mass with some power optimization
Shielded Volume	*kg/m3*	215.5	0.5	107.8	1	215.5
Power	*kg/kW*	237	0.220	52.1	0.220	52.1
Cooling	*kg/kW*	60	0.220	13.2	0.220	13.2
Equipment Mass	*kg*	1	60.0	60.0	80.0	80.0
			Total ESM	**233.1**		**360.8**

Water Recovery Potential

Daily Consumption for 6 person crew (kg)	Total Recoverable Water Mass for Transit Duration	Equipment volume, mass, or power
1.691	**1217.5**	Not Applicable

Savings from Waste Volume Reduction

The Maritime Pollution Act manually compacted density and Skylab compacted trash density were almost identical at approximately 64 kg/m3

Daily trash accumulation using manual compaction methods for 6 person crew (m^3)	Total trash accumulation over 360 days using manual compaction methods (m^3)	ESM value using current figures for Mars transit (kg)	Volume Reduction Factor based on Experimental Test unit tests	The final volume of the total trash accumulation after undergoing Plastic Waste Processor reduction (m^3)	ESM after undergoing Plastic Waste Processor reduction (kg)	ESM savings after undergoing Plastic Waste Processor reduction (kg)
0.09	32.4	6982	>10:1	3.24	698	**6284**

Table 1. Mars Transit ESM Study of PMWC

Note: The ESM factors were extracted from Advanced Life Support Baseline Values and Assumptions Document [9].

Sample #	Polyethylene (grams)	Polypropylene (grams)	Polystyrene (grams)	Meat (grams)	Lettuce (grams)	Bread (grams)	Duct Tape (grams)	Nitrile Gloves (grams)	Paper (grams)	Cotton Cloth (grams)	Total Sample Weight (grams)
1	10.66	-	-	-	-	-	-	-	-	-	10.66
2	10.77	-	-	-	-	-	-	-	-	-	10.77
3	10.68	-	-	-	-	-	-	-	-	-	10.68
4	10.63	-	-	-	-	-	-	-	-	-	10.63
5	10.75	-	-	-	-	-	-	-	-	-	10.75
6	10.47	-	-	-	-	-	-	-	-	-	10.47
7	10.60	-	-	-	-	-	-	-	-	-	10.60
8	10.46	-	-	-	-	-	-	-	-	-	10.46
9	10.72	-	-	-	-	-	-	-	-	-	10.72
10	10.62	-	-	-	-	-	-	-	-	-	10.62
11	18.77	-	-	-	-	-	-	-	-	-	18.77
12	19.71	-	-	-	-	-	-	-	-	-	19.71
13	24.88	-	-	-	-	-	-	-	-	-	24.88
14	24.83	-	-	-	-	-	-	-	-	-	24.83
15	24.94	-	-	-	-	-	-	-	-	-	24.94
16	25.41	-	-	-	-	-	-	-	-	-	25.41
17	23.48	-	-	-	-	-	-	-	-	-	23.48
18	23.07	-	-	-	-	-	-	-	-	-	23.07
19	29.27	-	-	-	-	-	-	-	-	-	29.27
20	19.11	9.34	3.09	-	-	-	-	-	-	-	31.54
21	2.44	7.29	14.65	-	-	-	-	-	-	-	24.38
22	3.82	2.91	0.68	2.81	3.70	2.80	-	0.22	3.47	-	20.41
23	4.19	2.03	0.74	2.31	3.05	2.40	0.83	0.23	3.62	6.00	25.40
24	4.11	2.08	0.71	2.30	3.04	2.33	0.91	0.22	3.61	6.07	25.38
25	6.83	0.00	0.00	2.31	3.05	2.31	0.78	0.21	3.59	6.06	25.14
26	6.86	0.00	0.00	2.32	3.06	2.33	0.90	0.23	3.62	6.05	29.18
27	9.28	0.00	0.00	2.29	3.01	2.38	0.81	0.23	3.62	6.12	27.74
28	0.00	0.00	10.46	0.00	0.00	0.00	0.00	0.00	5.57	9.18	25.21
29	15.97	-	-	-	-	-	-	-	-	-	15.97
30	15.69	-	-	-	-	-	-	-	-	-	15.69
31	8.83	1.12	0.42	1.37	2.88	1.42	0.40	0.13	2.02	3.30	21.89

Table 2. Plastic Characterization Testing Showing Waste Components and their Respective Masses

Sample #	Piston Diameter (in^2)	Load Pressure (psi)	Target Temperature (°C)	Sample #	Average Dwell Temperature (°C)
1	1.420	78.9	100	1	106
2	1.420	78.9	100	2	103
3	1.420	11.1	100	3	103
4	1.420	11.1	100	4	103
5	1.420	11.1	105	5	103
6	1.420	11.1	105	6	107
7	1.420	78.9	105	7	105
8	1.420	78.9	105	8	106
9	1.420	11.1	105	9	107
10	1.420	11.1	135	10	135
11	1.800	10.7	135	11	135
12	1.800	49.1	135	12	136
13	1.800	6.9	110	13	111
14	1.800	49.1	110	14	113
15	1.800	6.9	110	15	111
16	1.800	49.1	110	16	112
17	1.800	49.1	150	17	150
18	1.800	49.1	150	18	150
19	1.800	49.1	175	19	174
20	1.800	49.1	121	20	119
21	1.800	49.1	121	21	121
22	1.800	49.1	121	22	122
23	1.800	49.1	135	23	133
24	1.800	49.1	177	24	180
25	1.800	49.1	135	25	141
26	1.800	49.1	135	26	136
27	1.800	49.1	135	27	137
28	1.800	49.1	135	28	137
29	1.800	49.1	100	29	100
30	1.800	49.1	110	30	111
31	1.800	49.1	180	31	179

Table 3. Plastic Characterization Testing Showing Pressure and Dwell Temperatures

Sample #	Plastic Disk Final Volume (m^3)	Plastic Disk Final Weight (grams)	Plastic Disk Final Density (kg/m^3)	Densities of Pre-Processed Waste (kg/m^3) **see note below*	Compaction factor based on Trash Model Pre-Processed Densities (kg/m^3)
1	1.17E-05	10.63	909	62	15
2	1.56E-05	10.67	684	65	11
3	1.63E-05	10.75	661	65	10
4	2.39E-05	10.63	445	69	6
5	4.16E-05	10.72	258	65	4
6	2.12E-05	10.47	494	63	8
7	2.40E-05	10.59	441	64	7
8	1.38E-05	10.46	759	66	12
9	4.15E-05	10.71	258	68	4
10	na	na	na	na	na
11	7.92E-05	18.77	237	66	4
12	5.66E-05	19.71	348	65	5
13	7.32E-05	24.90	340	68	5
14	4.79E-05	24.74	517	65	8
15	1.15E-04	24.88	216	63	3
16	6.33E-05	25.40	401	67	6
17	5.11E-05	23.38	457	62	7
18	3.52E-05	23.03	654	61	11
19	2.95E-05	29.28	991	66	15
20	4.49E-05	31.54	703	68	10
21	3.23E-05	24.38	754	67	11
22	2.32E-05	13.95	600	67	9
23	3.67E-05	19.44	529	65	8
24	3.26E-05	19.38	595	63	10
25	2.83E-05	19.38	686	64	11
26	3.07E-05	24.73	805	64	13
27	3.21E-05	22.64	706	64	11
28	4.37E-05	24.27	556	71	8
29	6.39E-05	15.97	250	66	4
30	1.78E-05	15.69	879	63	14
31	1.48E-05	13.61	921	65	14

Table 4. Plastic Characterization Testing Showing Compaction Factors

• **Note:** The initial densities shown are based on the placement of the samples in a cylinder that was 2.9 inches in diameter by 3.8 inches in height. The initial density values shown in table 7 are based on the mass of the samples verses the volume of the cylinder. In some cases there were voids between the wastes that could not be eliminated due to the springiness of the material.